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Explanatory Value in Context
The Curious Case of Hotelling's Location Model

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Abstract

There is a striking contrast between the significance of Harold Hotelling's contribution to industrial economics and the fact that his location model was invalid, unrealistic and non-robust. It is difficult to make sense of the explanatory value of Hotelling's model based on philosophical accounts that emphasize logical validity, representational adequacy, and robustness as determinants of explanatory value. However, these accounts are misleading because they overlook the context within which the explanatory *value added* of a model is apprehensible. We present Hotelling's model in its historical context and show why it is an important and explanatory model despite its apparent deficiencies.

Keywords: Spatial competition, Harold Hotelling, Hotelling model, product differentiation, principle of minimum differentiation, explanatory value, representational adequacy, robustness, logical validity.

JEL Codes: B00, B21, B31, B41, L10

Introduction

In 1929, Harold Hotelling published what was to become a highly influential paper in economics: Stability in Competition, in which he presented a simple model of competition between two sellers selling an identical product in a linear and bounded market. The model, according to Hotelling, showed why "buyers are confronted everywhere with an excessive sameness" (1929, 54, emphasis added). This result is today known as the principle of minimum differentiation (also known as the Hotelling Law, Boulding 1966, 484). In his early textbook treatment of the model, Kenneth Boulding called this "a principle of the utmost generality" (1941, 601). Hotelling's model sparked the development of a large literature on spatial competition and product differentiation, inspired the development of spatial models of political competition, and became an indispensable part of economics teaching. Nevertheless, the early reception of Hotelling's model was not as positive as one might expect. Its early reviewers thought that the model was logically flawed, highly unrealistic, and very sensitive to changes in its assumptions (i.e., it was not derivationally robust; Woodward 2006). In fact, 50 years after the publication of Hotelling's article, D'Aspremont, Gabszewicz and Thisse (1979) demonstrated the invalidity of his results. As Hotelling's student Kenneth Arrow put it,

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"unfortunately, Hotelling's work on the economics of spatial location was vitiated by an error" (Arrow and Lehmannn 2005, 224).

There is a striking contrast between the significance of Hotelling's contribution to modern industrial economics and the fact that his original model was logically flawed, highly unrealistic and non-robust. Common sense suggests that a model with these characteristics cannot be explanatory. This view is generally supported by philosophical accounts of models that regard the logical validity, representational adequacy, and robustness of a model as determinants of its explanatory value. If one adopts this view, it is hard to make sense of the explanatory value of Hotelling's model and its significance in industrial economics.

In the present paper, using Hotelling's model as our case, we argue that there is more to the explanatoriness of a model than its logical validity, realisticness and robustness. Our argument is methodological, but it utilizes the history of economic thought and emphasizes its importance for economic methodology. We argue that to fully appreciate the explanatory import of a highly abstract theoretical model, philosophers of economics should pay attention to its historical context, particularly to the cluster of relevant models and explanations. It is possible to consider the present paper as an exercise in an integrated history and philosophy of economics. One shortcoming of this approach is that the resulting analysis might not appear to be historical enough for a historian or philosophical enough for a philosopher. Nevertheless, we hope to show that this integrated approach contributes to a better understanding of the explanatory import of theoretical models in economics such as Hotelling's model. Our analysis illustrates why the history of economics is essential to our understanding of modern economics: even a little bit of historical context, which includes information about the intended use of a model, its reception and the state of knowledge at the time, significantly improves one's understanding of a model. Moreover, we also hope that our contribution shows "why it is still important to examine the works of past economists even when we, the moderns, pretend to know much better, both analytically and empirically, than them," as one of the anonymous referees of the paper said.

With respect to our case, Hotelling's location model, we argue the following. Despite its apparent deficiencies, it emerged as an important explanatory model because it expanded the *menu of possible explanations* in the theory of imperfectly competitive markets by

(a) challenging the presumptions concerning the welfare implications of profit-maximizing behavior in real world markets,
(b) proposing *a new theoretical explanation* of the stability of competition in models of imperfect competition,
(c) expanding the set of *explanantia* by suggesting a set of new explanatory factors,
(d) expanding the set of *explananda* by alerting economists to *observations in need of explanations*, and
(e) functioning as a workhorse model, or a modeling framework that turned out to be useful in analyzing other aspects of imperfectly competitive markets.

Our argument proceeds as follows. First, we briefly present Hotelling's model. Second, we give an overview of its early reception. Third, we argue that it is difficult to see its explanatory

value if one follows the usual practice of analyzing the logical validity, representational adequacy, and robustness of a model in isolation from its historical context. Fourth, we present Hotelling's model in its historical context and explain why it was an important and explanatory model despite its apparent deficiencies. Finally, we present our concluding observations.

The original Hotelling model

Let us introduce Hotelling's original model briefly, starting with a list of its important assumptions. (1) The market is a straight line of a certain length—as illustrated in *Figure 1*. (2) There are two sellers,[2] A and B, who sell an identical product at different locations. (3) The cost of production is zero. (4) Consumers are distributed uniformly on the market line. (5) "[U]nit quantity of the commodity is consumed in each unit of time in each unit of length of line" (Hotelling 1929, 45). (6) Demand is perfectly inelastic. (7) Each consumer faces a transportation cost, which is a linear function of the distance between the consumer and the producer. (8) Consumers buy from the least costly seller; that is, they buy the product which costs less in terms of price plus transportation costs. (9) Sellers aim at profit-maximization. (10) In choosing their price or location, each seller assumes that the other's price and location will not change. (11) Sellers cannot cooperatively fix prices.

Figure 1

Given these assumptions, Hotelling showed that the profit of a seller depends on the price of its product and the share of the market it commands.[3] Thus, in the model, each seller has an incentive to lower its price, change its location, or both.

Hotelling first analyzed the stability of prices *given the locations* of the sellers. He argued that if each seller tries to determine the best price, *given the competitor's price*, this would trigger a process of price adjustment that would lead to a stable equilibrium.[4] However, Hotelling was quite cautious about the result concerning the stability of prices and equilibrium. He pointed out the possibility that "prices other than" equilibrium prices "may obtain for a considerable time" (Hotelling 1929, 48). He noted that sellers might take advantage of the inelasticity of demand by "exploiting the consumers without limit by raising their prices" (1929, 48), but dismissed this possibility because of the "difficulties of maintaining a price-fixing agreement" (1929, 48). Hotelling (1929, 49) also noticed that the details of the price adjustment process would depend on market conditions, but he omitted these details in order to focus on the question of stability. Finally, he admitted the possibility of a price war, but argued that this was not important for the study of stability, claiming that, "[this] possibility does not affect the argument that there is price stability, since stability is by definition merely

[2] In what follows we will use producer, seller and firm interchangeably.
[3] For textbook versions of the model see Frank (2008), Nicholson and Synder (2010), Pepall, Richards and Norman (2014), Shy (1995), Tirole (1988), and Varian (2014).
[4] Note here that Hotelling's analysis focuses on equilibria in pure strategies.

the tendency to return after *small* displacements. A box standing on end is in stable equilibrium, even though it can be tipped over" (1929, 50).

Having established the stability of prices, Hotelling asked what would happen if one seller were able to change its location. Consider the two sellers in *Figure 1* again. *A* is selling to customers who occupy the ($x + a$) portion of the line, and *B* is serving to customers on ($y + b$). If we allow *B* to move—keeping *A*'s location fixed—it is obvious that *B* would have an incentive to move as close as it can to *A* in order to make *b* and its profit as large as possible (see *Figure 2*). Hence, Hotelling argued, each seller would *tend to* move next to the other given prices and the other seller's location. He, however, did not show that the sellers would locate at the center of the market.[5]

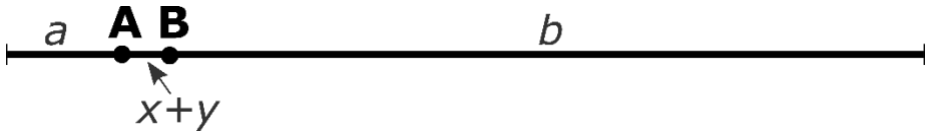

Figure 2

Notice in *Figure 2* that the sellers are very close to each other, but do not occupy the same location. Hotelling argued that if both sellers were to occupy the same location, they would need to decrease their prices in order to increase the number of their customers. This would lead to a price war, and the attainment of price stability would not be warranted. However, Hotelling's analysis was not clear about why the sellers who engaged in a price war when they were at the same location would not do this when they were very close to each other. In addition, he did not explain how large the cushion between the sellers should be.

Nevertheless, he showed that sellers would tend to move next to each other. What did this mean? First, according to Hotelling, it illustrated a more general tendency—if differences in location are interpreted as differences in products:

> The mathematical analysis thus leads to an observation of wide generality. Buyers are confronted everywhere with an *excessive sameness*. When a new merchant or manufacturer sets up shop he must not produce something exactly like what is already on the market or he will risk a price war […]. But *there is an incentive to make the new product very much like the old*, applying some slight change which will seem an improvement to as many buyers as possible without ever going far in this direction. (Hotelling 1929, 54, emphasis added)

Second, it showed the "wastefulness of private profit-seeking management", because it increases the total transportation costs paid by consumers, compared to an alternative solution where sellers locate at "symmetrical positions at the quartiles of the market" (1929, 53).

In sum, these were the main results of Hotelling's model: stability of prices, excessive sameness (minimum product differentiation), and wastefulness of competition.

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[5] It was Edward Chamberlin (1933) who showed that in pure spatial competition (i.e., with fixed prices), the equilibrium would be at the center of the market.

The early reception of Hotelling's model

Hotelling's location model sparked the development of a large literature on spatial competition and product differentiation (for a review, see Biscaia and Mota 2013). It inspired the development of spatial models of political competition (e.g., Downs 1957; Osborne 1995; Osborne and Slivinski 1996). Versions of it have become indispensable parts of *industrial organization* textbooks at the intermediate (e.g., Shy 1995; Pepall, Richards, and Norman 2014) and advanced levels (e.g., Tirole 1988). The model's main result is also presented to students in intermediate microeconomics lectures and textbooks (e.g., Frank 2008; Nicholson and Snyder 2010; Varian 2014). It is therefore hard to overstate the significance of Hotelling's model. It is commonly considered an important and explanatory model. Nevertheless, its early reception was not as favorable as one might expect. Early commentators focused on three aspects of Hotelling's model: its validity, representational adequacy and robustness. We discuss these in order.[6]

Logical validity

Unlike the textbook versions of the model (e.g., Varian 2014), Hotelling did not assume that prices were fixed. However, when sellers can compete both in price and location, Hotelling's results are not as easy to derive as in the textbook versions. The difficulty of determining the equilibrium and the possibility of a price war between sellers did not go unnoticed by early commentators.[7] For example, both Palander (1935) and Lösch (1954) pointed out this possibility. Similarly, Arthur Smithies (1941) argued that if each seller acts as if the other would keep its price and location fixed, as assumed by Hotelling, equilibrium might not be possible under all conditions, and that "the possibilities of economic warfare must be considered" (1941, 428). He argued that "equilibrium at the center would be stable only if one assumes that each competitor sells only in his own hinterland and does not attempt to invade the hinterland of his rival" (1941, 434). Gardner Ackley (1942) also noticed that there was "no reason, however, for assuming that any equilibrium (in the sense of a stable pair of prices) will ever be attained" (1942, 226). In fact, he argued that "a continuous series of price fluctuations would seem inevitable, as long as we require the sellers to cling rigidly to the assumption that the rival's price is given" (1942, 227). It is also worth noting that Kenneth Boulding, who did not discuss the difficulty in determining the equilibrium and the possibility of a price war in the early editions of his textbook (1941), introduced the possibility of a price war in later editions (1966).

Other commentators, such as John Hicks, Abba Lerner, Hans Singer and Austin Robinson, focused on other aspects of the model—some of which we will discuss later on—but they did

[6] As one of the anonymous referees of this paper rightly pointed out, for the modern reader who is well versed in game theory this early debate might appear to be blurred by misunderstandings concerning what a strategic environment is. Note however that this literature predates the surge of non-cooperative game theory. The same applies to the discussion concerning conjectural variations (see Giocoli 2003, 2005 for the debate concerning the conjectural variations approach).

[7] Although the difficulty of determining the exact equilibrium point in the case of product differentiation was noticed by Edward Chamberlin (1933) in his own analysis of monopolistic competition, he did not pay enough attention to the difficulties presented by Hotelling's model.

not question the validity of the original model (Hicks 1935; Lerner and Singer 1937; A. Robinson 1941; Zeuthen 1933; Chamberlin 1933).

In sum, there was a dim suspicion that Hotelling's results could not be inferred from his assumptions, and that there was a logical flaw in the model that invalidated its results. It took fifty years before a definitive proof of the fault in Hotelling's model was demonstrated. In a well-known paper, D'Aspremont, Gabszewicz, and Thisse (1979) showed that Hotelling's main and famous result was simply wrong. They proved that the model had no equilibrium price solution when sellers were close to each other. They also established that an equilibrium could be attained if one assumed quadratic transportation cost functions, rather than linear ones. However, this equilibrium would be that of maximum product differentiation, rather than minimum product differentiation—which obviously contradicts Hotelling's results.

Despite its intuitive appeal, Hotelling's model did not have logical validity; its results did not follow from its assumptions.[8] As Hotelling's student and Nobel laureate economist Kenneth Arrow put it, "Unfortunately, Hotelling's work on the economics of spatial location was vitiated by an error" (Arrow and Lehmannn 2005, 224).

Representational adequacy

The early reception of Hotelling's model was also characterized by commentary concerning the unrealisticness of its assumptions. A few examples will be sufficient to show this. Lerner and Singer thought that Hotelling's assumption concerning the inelasticity of demand was unrealistic, suggesting that "if we are going to be at all *realistic*" it is necessary "to assume an upper limit to the price each buyer is willing to pay" (Lerner and Singer 1937, 148 emphasis added). Austin Robinson reasoned that Hotelling's results were paradoxical and they "would have disappeared if other, and more realistic, assumptions had been made" (A. Robinson 1941, 270). Gardner Ackley complained about "the *ridiculousness* of" the assumption that each seller takes the rival's price as given (1942, 225 emphasis added). Lösch argued that "with *even a slight degree of realism*, no such tendency to agglomeration conditioned by freight cost exists" (Lösch 1954, 75, emphasis added). In sum, many thought that Hotelling's assumptions concerning the elasticity of demand (Lerner and Singer 1937; A. Robinson 1941; Smithies 1941; Ackley 1942; Lösch 1954), the number of sellers (e.g., Chamberlin 1933; Lösch 1954; Hicks 1935), the behavior of the sellers and especially their lack of foresight (e.g., Lösch 1954; Smithies 1941) were unrealistic.

Robustness

The unrealisticness of Hotelling's assumptions was especially worrying because making these assumptions more realistic invalidated his results. The model's results were very sensitive to alterations in its assumptions; they were not robust.

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[8] This is well known to specialists in the field. For example, Eiselt (2011, 153) notes that the model contained an "inconsistency that invalidated Hotelling's main result", Hamilton, MacLeod and Thisse (1991, 925) note that "Hotelling's original solution" is "incorrect", and Kats (1995, 89) argues that "it is well known that Hotelling's model of spatial competition has no location-price equilibrium in pure strategies" (also see Eaton and Lipsey 1989, 749; Church and Ware 2000, 403).

First, the model's results were sensitive to changes in the number of firms and bounds of the market. As early as 1933, Chamberlin observed that the models' finding concerning minimum differentiation did not hold once a third seller was introduced into the market. Chamberlin noted, however, that if the number of sellers was more than three, some sellers could group together but the groups would be dispersed. Similarly, Hicks (1935) argued that *under more realistic conditions* (e.g., more than three firms, and competition in location and quality) the outcome would be dispersion rather than agglomeration. Both Chamberlin and Hicks thought that Hotelling's results were not general.

Later, Chamberlin (1953) added that Hotelling's result was an artefact of the bounded market assumption. He argued that if we got rid of this assumption by, for example, assuming a circular market, Hotelling's results would not hold (Chamberlin 1953, 20–21). Likewise, Lösch (1954, 75) argued that if the bounds of the market were stretched or removed, Hotelling's results would not hold. Although Boulding did not consider the limitations of Hotelling's model in the earlier editions of his textbook (1941), in later editions he also introduced the "end problem" in his exposition. The main point was that minimum differentiation would not occur in an unbounded market; instead, sellers would locate themselves away from their competitors (Boulding 1966, 483).

Second, modification of the inelasticity assumption changed the results of the model. Lerner and Singer showed that if an "upper limit to the price each buyer is willing to pay" were introduced to the model, Hotelling's results would not hold (1937, 148). Austin Robinson, who thought Hotelling's results were paradoxical, argued that Hotelling's model represented a "very special and exceptional case" (1941, 275) and that its results could not be generalized. In particular, he argued that modifying the assumptions concerning zero production costs and inelasticity of demand would produce different results. Arthur Smithies (1941), who tried to generalize Hotelling's results, found that Hotelling's results were partially due to the assumptions concerning inelasticity of demand and the specific way that sellers were assumed to behave in the model. He also studied the effects of changes in transportation costs and marginal costs, showing that when demand was elastic, transportation costs played an important role in determining the location of competitors. The lower the transportation costs, closer the sellers were to the center. As transportation costs increased, they moved away from the center. Moreover, Smithies considered what would happen if there were a small change in marginal costs for both sellers. He argued that an increase in marginal costs for both sellers meant that they would move further away from the center of the market. With a sufficiently large increase in marginal costs, sellers would move to the quartiles of the market. In sum, he showed that Hotelling's results were sensitive to changes in his model's assumptions.

Following the footsteps of earlier economists, particularly of Chamberlin and Palander, Lösch (1954) also showed that if inelastic demand was replaced by elastic demand, sellers would locate at the quartiles of the market, not at the center. Two early game-theoretical treatments of Hotelling's model made similar points concerning the assumption of inelasticity. Both showed that Hotelling's results would change once elastic demand was assumed (Stevens 1961; Isard and Smith 1967).

Hotelling's model was sensitive to alterations in its other assumptions too. In 1975, Curtis Eaton and Richard Lipsey published an extensive review of the literature on the principle of minimum differentiation and offered their own analysis. They showed that Hotelling's results were sensitive to how the consumers were distributed in the market—even though Hotelling (1929, 55) thought that this assumption had no bearing on his model's results. They also demonstrated that the model's results were sensitive to a change in Hotelling's zero conjectural variation assumption. In sum, the model's results held under very specific conditions: two firms, zero conjectural variation and a bounded linear market where consumers were evenly distributed. As we have already seen, four years after Eaton and Lipsey's review, it turned out that with quadratic transportation cost functions Hotelling's model produced *maximum* product differentiation, rather than *minimum* product differentiation (D'Aspremont, Gabszewicz, and Thisse 1979).

In conclusion, early commentators thought that Hotelling's model lacked logical validity, representational adequacy, and robustness.

The explanatoriness of an invalid, unrealistic, non-robust model

Let us now pause here and consider the explanatory value of Hotelling's original model from the point of view of the philosophy of science. In assessing the epistemic value of highly unrealistic theoretical models, philosophers of science commonly ask the following questions.

(i) *Logical validity.* Is the model logically valid? Do its results follow from its assumptions?
(ii) *Representational adequacy*. Is the model similar in relevant respects and sufficient degrees to its intended real-world target? Is it representationally adequate?
(iii) *Robustness*. Are the results of the model robust to changes in its assumptions?

Of the three criteria, logical validity is the least controversial. It is generally assumed that if the model has a logical flaw, it cannot be a useful model in any important sense. The logical validity of models is commonly presumed as a virtue without much discussion. Philosophical intuition concerning the criterion of logical validity is quite straightforward: if the results of a theoretical model, such as Hotelling's, do not follow from its assumptions, the model and its results cannot be trusted as a guide to the relevant parts of the real world.

The second criterion is representational adequacy. Theoretical models in economics are frequently deemed representationally inadequate, because their assumptions do not provide good descriptions of the real world. The long history of debates concerning the realisticness of economic models is full of examples (e.g., *the marginalism debate* and the related 'realism' of assumptions debate). Critics of economics often base their criticism on the unrealisticness of economic models (e.g., Keen 2011). However, valuing representational adequacy is not a peculiarity of the critics of economics. Most philosophers of science also presume that the explanatory value of a model depends critically on its representational adequacy, or on the similarity between a model and its real-world target (e.g., Giere 1988, 2004, Mäki 1992, 2009). The intuition here is again simple: if the model is not sufficiently similar to the part of the real

world that it wishes to explain, the lessons we learn by studying the model cannot be explanatorily relevant.

The third criterion, robustness, supplements the first two. Even if a model is logically valid, and representationally adequate, it may fail to be explanatory. Many philosophers and economists think that a good model should also be robust to alterations in its simplifying assumptions such as tractability assumptions (Cartwright 2007, 2009; Kuorikoski, Lehtinen, and Marchionni 2010; Gibbard and Varian 1978). Philosophers of science commonly argue that robustness gives us some confidence that a model's results are not artefacts of the structure of the model. Thus robustness increases one's confidence in a model's results (Kuorikoski, Lehtinen, and Marchionni 2010). Economists seem to agree with this view (e.g., Gibbard and Varian 1978). The intuition is once again simple. If a model's results change radically when we alter its seemingly trivial assumptions, such as tractability assumptions, we cannot trust that its results will hold in the real world, where many of the model's assumptions do not hold. Such a model can only be applicable to real-world cases where all of its assumptions hold. Hence, non-robustness hinders the generality and applicability of the model.

Given the criteria of logical validity, representational adequacy and robustness, Hotelling's does not appear to be an explanatory model. In fact, based on these criteria, Julian Reiss (2012), a philosopher of economics, argues that Hotelling's model cannot be explanatory. Shall we then conclude that it has no explanatory value? Our answer is no, for the following simple reason: there is more to the explanatory value of a model than its logical validity, representational adequacy, and robustness.

Carrying out an analysis of explanatory value based on these criteria often leads one to ignore how the model of interest is related to other models and explanations. First, one needs nothing but the model in order to analyze its logical validity. Logical validity is about the internal characteristics of *a* model; hence, one does not need to consider other related models and explanations in order to reach a verdict about logical validity. Second, questions concerning representational adequacy require a model-target comparison, and do not necessitate considering a model in the context of other relevant models and explanations. In practice too, questions about representational adequacy are commonly answered by singling out a model and comparing it to a real-world target. Debates concerning the realisticness of assumptions and representational adequacy rarely consider a model in relation to other relevant models and explanations. That is, a model's explanatory import is commonly analyzed *in isolation from* other related models and explanations and historical context. The only criterion that requires one to consider models that relate to the original model of interest is robustness. However, in the case of robustness analysis, it is sufficient to consider those models that are slightly different from the original model. There is no need to consider other related but considerably different models, nor it is required to take into account relevant explanations or the historical context.

Consequently, philosophers and critics of economics who base their analysis on these criteria commonly evaluate a model's explanatory value in isolation from other related models and explanations. Moreover, historical context rarely enters the picture. In what follows, we

show that to appreciate the explanatory import of a theoretical model fully, we need to consider it in its historical context, particularly that of relevant models and explanations. Our case in point is Hotelling's model.

Reappraisal of Hotelling's model

Simply put, a model has explanatory value if it helps us provide explanations, or if it provides us with explanatorily relevant information. In order to properly understand the explanatory *value added* of a theoretical model, such as Hotelling's, we need to evaluate it in its relevant context. Particularly, we need to understand how it expands *the menu of possible explanations* available to economists (Ylikoski and Aydinonat 2014). Theoretical models could expand the menu of possible explanations by way of suggesting new explanatory factors (*explanantia*) or observations in need of explanations (*explananda*), or both. If a theoretical model is able to expand the menu of possible explanations, it could also improve the ability of economists to provide explanations for particular observed facts or events.

In this section, we present Hotelling's model in its relevant context (of relevant models, explanations and debates), and show that despite its deficiencies, it is an explanatory model. We also explain why economists consider it an important model. In order to accomplish this, we consider some of the models, explanations and theoretical problems prior to Hotelling's contribution. This helps us to show what the original Hotelling model was meant to contribute to our understanding. We also assess Hotelling's model in the light of the relevant literature after Hotelling. This helps us discuss the actual explanatory contribution of Hotelling's model.

The context

The background of the Hotelling model was a quest to understand the nature of competition, and thus a family of models of competition ranging from monopoly to perfect competition. Augustin Cournot's (1838) analysis was an important keystone. Cournot's original duopoly model[9] assumed that there are two identical producers who produce identical products at zero cost, and face the same demand. In order to focus on competition among the producers, Cournot assumed away the possibility of producers acting together in order to maximize their profits. Thus, he assumed that producers act independently from each other. In what looks like a sequential game, at each step one producer responds to what the other did in the previous period—ignoring how her own actions would influence the other producer (Giocoli 2003; Dimand and Dimand 1996). Cournot argued that when the producers think and act in this way they will end up in a stable equilibrium. This equilibrium represented a case (duopoly) between pure monopoly and competition. In his review of Cournot's book, Joseph Bertrand (1883 [1989]) argued that Cournot's model was *mistaken* in that price competition among duopolists would not lead to a stable equilibrium. Hotelling's model was a response to Bertrand's (1883 [1989]) criticism of Cournot's (1838) duopoly model.

[9] Note that the original model is different from the textbook Cournot model in that it does not assume that the prices are fixed. There are also other differences between the textbook presentation and the original model (for a detailed discussion see Giocoli 2003; Bornier 1992; Dimand and Dimand 1996).

Cournot analyzed the results of profit-maximizing behavior under different conditions, ranging from monopoly to perfect competition, and invented the theory of pure monopoly and duopoly. "He also planted the idea that perfect competition is the limiting case of the entire spectrum of market structures" (Blaug 1985, 319). Thus, in addition to the question concerning the stability of equilibrium, a second and more general question was about the range of outcomes that would prevail in different types of markets (i.e., monopoly, oligopoly, perfect competition; each with a different model) and under different conditions for each market type. Following Cournot, later economists used their existing analytical tools and developed new ones in order to answer these questions. More properly, they asked and answered a series of *what if* questions (Ylikoski and Aydinonat 2014) concerning markets and competition; exploring the model worlds that their predecessors had cultivated. For example, Francis Ysidro Edgeworth (1881) explored Cournot's model and argued that Cournot's result for the duopoly case would not obtain under certain conditions. In an article published in the same year as Hotelling's model, Edward Chamberlin explored what would happen under different conditions (asking *what if* questions) and reached the following verdict. "Duopoly is not one problem, but several. The solution varies, depending upon the conditions assumed" (1929, 91). Like Cournot, Edgeworth, and Chamberlin, Hotelling was also trying to understand how competition driven by the economizing actions of firms and consumers would work under different conditions.

Hotelling also said that his model, which demonstrated "the wastefulness of private profit-seeking management" (1929, 53), was relevant to the "the question of capitalism v. socialism" (1929, 52). In fact, as Kenneth Arrow puts it, he was a socialist "who emphasized the role of the market even under socialism" (quoted in Klein 2013, 270). It is worth noting that the historical context of Hotelling's 1929 paper includes the Bolshevik revolution in 1917 and the publication of Misses's "Economic Calculation in the Socialist Commonwealth" in 1920 that ignited the socialist calculation debate (Backhouse 2003, 319). But more relevant to Hotelling's model was the trade association movement in the USA (Sharfman 1926; Compton et al. 1926) and the new economics thinking of the 1920s (Barber 1985), not to mention the publication of John Maynard Keynes' *The End of Laissez-faire* in 1926 (Keynes 1978). As Barber argued, although the emerging economics doctrine of 1920s "was not codified in any single document," there was a "reasonably coherent implicit model" (1985, 4). This 'model' maintained that perfect competition does not necessarily serve the public interest, and that it can be wasteful. Trade associations were believed to eliminate the wastefulness "of uncoordinated and unintelligent competition" (Sharfman 1926, 205). Moreover, according to Barber, there was also a general suspicion concerning the "conclusions derived from deductive theorizing" (1985, 4).[10]

It is within this context that Hotelling's location model showed the wastefulness of competition. Nevertheless, contrary to those who suspected the usefulness of abstract theorizing, he was committed to "the erection of a rigorous theoretical framework for

[10] On the life and works of Harold Hotelling see Olkin (1960), Arrow (1989), Darnell (1988, 1990), and Arrow and Lehmann (2005).

economics" (Darnell 1990, 22). His model was an attempt to explore the world of imperfect competition. Hotelling believed that the type of competition presumed by laissez-faire arguments did not provide a good description of real markets. He said,

> In asserting that a maximum of total satisfactions is to be reached by laissez-faire, it is usually forgotten that the proof of the statement calls for the *competition of a type not found in large-scale modern industry*. (Hotelling, from an unpublished manuscript "Prosperity through increased production", quoted in Darnell 1990, 22 emphasis added)

He thought that real-world markets lay between perfect competition and pure monopoly (1929, 44). However, in economics, there was a large *unmapped territory* between these two extremes. Exploring this territory required more than just building new models within the existent framework. Firstly, economists needed to revise some of their assumptions. Secondly, they needed to develop new ideas and frameworks in order to account for the facts that existing models could not explain. Hotelling was innovative in both respects.

Reformulating the principle of one price

An important question that characterized the theoretical landscape before the publication of Hotelling's article was how to conceptualize imperfect competition. One of the main debates concerned Alfred Marshall's (1890) (and his follower Arthur C. Pigou's) accounts of competition in the presence of increasing returns. Moreover, the so-called cost controversy starting with Clapham's (1922a) provocative article entitled "Of Empty Economic Boxes" considered precisely the nature of competition and applicability of economic models to the real world (on the cost controversy, see Clapham 1922a, 1922b; Graham 1925; Knight 1924; Pigou 1922; Pigou and Robertson 1924; Sraffa 1926; Young 1928). The cost controversy "led to the development of analytic tools to deal with the problem of monopoly" (Backhouse 2003, 53) and with the problem of imperfect competition in general. In fact, "cost controversy did result in a better understanding of competitive theory" (Samuelson 1967 [2004], 412). Following the cost controversy—and after the publication of Hotelling's article—two important books on imperfect competition were published almost simultaneously, one by Edward Chamberlin (1933) and the other by Joan Robinson (1933), 95 years after Cournot's (1838) treatise.

In short, the 1920s was a time of hot debate concerning economic theory and its success in explaining real-world competition.

At the beginning of the 1900s, Henry Moore (1906) argued that in order to understand imperfect competition, the presumptions of existing models needed revision and change. One assumption that needed reconsideration was the principle of one price, which was the source of the instability that Bertrand pointed out. According to this principle, it is impossible for producers to charge different prices for a homogenous product and keep their market share. If one producer charges a lower price than the other, consumers who are aiming to maximize their own gains will immediately switch to the cheaper producer and the competing firm will lose all of its customers. This will lead to a price war, and the equilibrium would be unstable: Bertrand argued, "with this hypothesis a solution is impossible; the price reduction would have

no limit" (1883 [1989], 77). Hotelling set out his analysis in order to point out the further possibility that producers are able to charge different prices.

> However, one important feature of actual business seems until recently to have escaped scrutiny. This is the fact that of all the purchasers of a commodity, some buy from one seller, some from another, in spite of moderate differences of price. If the purveyor of an article gradually increases his price while his rivals keep theirs fixed, the diminution in volume of his sales will in general take place continuously rather than in the abrupt way which has tacitly been assumed. A profound difference in the nature of the stability of a competitive situation results from this fact. (Hotelling 1929, 41)

In this context, Piero Sraffa's (1926) contribution to cost controversy appears to be particularly important. Hotelling refers to him in support of the idea of reformulating the principle of one price.

> The feature of actual business to which, like Professor Sraffa, we draw attention, and which does not seem to have been generally taken account of in economic theory, is the existence with reference to each seller of groups of buyers who will deal with him instead of with his competitors in spite of a difference in price. (Hotelling 1929, 44)[11]

In sum, given the available family of models of competition, the idea that one should abandon or reformulate the principle of one price in order to understand some cases of imperfect competition was extremely important. What made Hotelling's model special was the way in which he implemented this idea and its promise to explain previously unexplained phenomena.

Spatial competition and excessive sameness

Hotelling made two important observations. First was the reason why he wished to reformulate the principle of one price: "the fact that", despite differences in price, some people prefer to buy a good from one seller rather than another (1929, 41). The second observation was the existence of "tremendous standardisation" in certain markets and the "tendency" of producers "to make only slight deviations in order to have for the new commodity as many buyers of the old as possible" (1929, 41). Hotelling argued,

> So general is this tendency that it appears in the most diverse fields of competitive activity, even quite apart from what is called economic life. In politics it is strikingly exemplified. (Hotelling 1929, 54)

These two observations were important because Hotelling thought that they would help him provide an answer to an important theoretical question that occupied the minds of previous economists: would a market with only a few producers reach a stable equilibrium? Hotelling also wished to explain the existence of excessive sameness in real markets. So, he not only

[11] Note here that Hotelling cited Sraffa because Keynes, who was the editor of the *Economic Journal* at the time, suggested that he should (Darnell 1990, 14). Of course, we cannot know whether Hotelling read Sraffa's contribution before constructing his model, but he could not be unaware of the debates at the time. In any case, his contribution was spot on given the context and interests of economists of the time.

proposed a new explanation of the stability of prices in a duopoly model, he also suggested a possible way in which economists could explain excessive sameness in markets, politics and elsewhere.

Reformulating the principle of one price and accounting for the fact that a consumer may prefer a more expensive product despite the fact that there is a cheaper alternative is not as easy a task as it may seem. In order to do this, Hotelling suggested an innovative way to analyze markets. He conceptualized the market as an extended region, and used the location of the producer (hence transportation costs) as a proxy for anything that could lead a consumer to prefer one producer to the other. This was an innovation, but not because Hotelling introduced space into an economic model. As Blaug (1985, 614) notes, spatial economics had its roots in Heinrich von Thünen's *Der isolierte Staat* (1910), published in 1826. Moreover, Wilhelm Launhardt's (1885) analysis of economic aspects of space precedes that by Hotelling. In fact, in some respects Launhardt's analysis can be considered as being more general than Hotelling's (Dos Santos Ferreira 1998). Nevertheless, while Launhardt is absent in modern industrial organization literature, Hotelling (1929) is one of the main references.[12] One reason for this is the way in which Hotelling utilized space in order to study all sorts of differences between products as well as producers (also see Dos Santos Ferreira 1998, 107). This was his innovation.

The use of location as a proxy for other differences turned Hotelling's model into a framework that can be utilized in modeling and explaining spatial competition, product differentiation, customer loyalty, the importance of advertising, or the ideological positions of competing political parties. Thus, Hotelling not only proposed a possible explanation for excessive sameness, he also introduced a *workhorse model* that could potentially explain a wide range of phenomena. He expanded the set of things that economics could explain; he expanded the set of *explananda*.

Hotelling's approach to the problem also revealed a type of profit which was hard to classify into existing categories at the time. Hotelling argued that while the profits of the competing sellers cannot be considered as "rents", they "may be classified as monopoly profits, but only if we are ready to extend the term 'monopoly' to include such cases […], involving the most outright competition for the marginal customer but without discrimination in his favour, and with no sort of open or tacit agreement between the sellers" (1929, 50–51). Thus, Hotelling alerted his fellow economists to a type of profit that may be brought about by product differentiation and the existence of a limited number of competitors. This was yet another observation in need of explanation and Hotelling's model proposed a possible explanation for it.

Remember also that Hotelling was interested in illustrating the stability of competition. By way of introducing product differentiation (using location as a proxy), he pointed out yet another difficulty in analyzing equilibrium. Chamberlin (1969, 73), for example, noted that

[12] For a philosophical analysis of von Thünen's spatial model, see Mäki (2011). For a review of the early history of spatial economics see Blaug (1985) and Ponsard (1983). For a comparison between Launhardt's and Hotelling's contributions, see Dos Santos Ferreira (1998).

only Hotelling noticed that when products and prices can be varied together, "product equilibrium needs explanation". Thus not only did Hotelling propose solving the existing theoretical problem of stability of competition, but he also transformed it into a question that seemed to have more real-world relevance. Although he failed to solve it, the problem itself was too important to be ignored.

Unlike the unforgiving critics of economics, or philosophers of economics who base their analysis solely on logical validity, representational adequacy and robustness, early commentators also thought that Hotelling's model was important. Consider, for example, the early textbook treatment of one of the main results of the model, the principle of minimum differentiation.

> This is a principle of the utmost generality. It explains why all the five-and-tens are usually clustered together, often next door to each other; why certain towns attract large numbers of firms of one kind; why an industry, such as the garment industry, will concentrate in one quarter of a city. […] It explains why all automobiles are so much alike, and why no manufacturer dares make a car in which a tall hat can be worn comfortably. It even explains why Methodists, Baptists, and even Quakers are so much alike, and tend to get even more alike, […]. It explains the importance of brand names in commercial, social, and even religious life, […]. Thus it also explains the importance of advertising […]. (Boulding 1941, 601)

It was not just Boulding who recognized the importance of Hotelling's model. In his discussion on the difficulties of measuring monopoly power, Lerner (1934) acknowledged the importance of location in creating a degree of monopoly power in the market. Similarly, Lerner and Singer (1937) emphasized the importance of the problem of space for economic theory. They also appreciated the convenience that Hotelling's model introduced by using location as a proxy to simplify the problem of product differentiation (Lerner 1934; Lerner and Singer 1937). Smithies (1941) welcomed Hotelling's attempt to capture one tendency, but pointed out the deficiencies of the model to suggest that another tendency should also be studied, arguing,

> I do not dispute Hotelling's conclusion that there is a tendency for two competitors to cluster nearer to the center than to the quartiles of a linear market; I suggest however, that it is important to analyze not only the forces that tend to bring them together but also those that keep them apart. (Smithies 1941, 423)

Perhaps the most telling example is Chamberlin's (1951) use of Hotelling's model in "Monopolistic Competition Revisited," in which he reformulated his own theory of monopolistic competition. To analyze the problem of product differentiation, he used a simple spatial competition model that was very similar to Hotelling's. The model helped Chamberlin justify his seemingly "paradoxical expression 'monopolistic competition'" (1951, 346), because it showed that there can be competition between sellers despite the existence of local monopolies. Chamberlin used this simple model, which was Hotelling's model in disguise, as a workhorse model to explore several *what-if* questions concerning monopolistic competition.

The fact that Chamberlin did not cite Hotelling in this article reveals that by 1951, Hotelling's model was perhaps already a part of the common knowledge of economists.

Hotelling was one of those economists who responded to the challenge of exploring the unmapped territory of imperfectly competitive markets. He challenged some existing assumptions and introduced a fresh way to look at competition that could shed some light on previously unexplained phenomena. The original model failed to show the stability of competition (because, as we have seen, it was mistaken), but it convinced its readers that the model and its set of *explanantia* was useful in understanding and explaining real markets and phenomena that go beyond markets.

The explanatory value of Hotelling's model

In order to fully appreciate the value of Hotelling's model, it is also useful to reconsider the criteria of logical validity, representational adequacy and robustness in the light of relevant models and debates introduced above. In what follows, we start with a discussion of representational adequacy. Based on this discussion we clarify why the logical flaw of the model did not matter much. We then explain why non-robustness might be considered as a virtue in Hotelling's case. Finally, we briefly consider the value of Hotelling's model in the context of modern industrial economics.

In assessing the representational adequacy of a model, it is important to understand what the model is trying to accomplish. Hotelling employed many unrealistic assumptions *in order to focus on* how location and related transportation costs could affect the market outcome. The model was not intended as *the* model of imperfect competition. It was *a* model that captures certain aspects of imperfectly competitive markets. A model that *could help* economists *explain* real world markets. This observation is important because, as recently argued by Dani Rodrik (2015), it is a mistake to treat *a* model as if it is *the* one and only model of the phenomenon at stake. Because economists try to make sense of the world with multiple models (Ylikoski and Aydinonat 2014; Rodrik 2015; Aydinonat 2018), it is important to consider what Hotelling's model added to the menu of explanations available to economists at the time—as we have done in the preceding pages.

Secondly, it is important to realize that most theoretical models do not explain real world phenomena straight out of the box. Rather they help us answer *what-if* questions (Ylikoski and Aydinonat 2014). Hotelling's model shared a core explanatory mechanism with other economic models: the economizing actions of individuals and firms. Given this familiar and real mechanism, Hotelling's model was yet another setup that was supposed to help economists investigate what would happen if spatial considerations (as a proxy for all sorts of reasons relating to differences in products) were important for economic agents. Hotelling's model captured and analyzed location and transportation costs, as well as other product differences, as important factors that may be relevant in explaining some features of imperfectly competitive markets, hence expanding the menu of possible explanations.

Thirdly, although Hotelling's model appears to be highly unrealistic, it is possible to imagine and even experimentally recreate a market like Hotelling's linear one. If you think that economizing action is a good approximation to the actions of real individuals, the possibility

of setting up an experiment like this offers additional assurance that the model has something to say about reality.[13] The way in which the textbook Hotelling model is introduced is revealing in this respect. Textbooks often invite students to imagine a real life situation like the case of two ice-cream vendors on a beach, and ask students what would happen if certain properties of the situation were changed (Varian 2014). It is worth noting here that although economists were not keen to design experiments concerning the Hotelling model (perhaps because the results of the experiment were obvious to them), the two experiments that we know of both support Hotelling's main results (Brown-Kruse, Cronshaw, and Schenk 1993; Anderson et al. 2006).

All this helps us understand why the logical validity of Hotelling's model did not matter much. One important reason is that Hotelling captured important real factors that *could* help economists explain economic phenomena. Even though the original model was mistaken, it was promising because it expanded the set of explanatory factors that economists could use, expanding the menu of possible explanations available to economists. Another reason is that it was a good workhorse model. By exploring Hotelling's model with additional *what-if* questions, economists confirmed that under certain special conditions Hotelling's results were valid and discovered that location (as a proxy for product differences) helped them to produce results that may explain other aspects of imperfectly competitive markets. The model provided possible ways to explain minimum product differentiation as well as maximum product differentiation. This last point relates to the robustness of Hotelling's result, which we discuss next.

The worry about the non-robustness of Hotelling's model was that the principle of minimum differentiation might be an artefact of the structure of the model, not a result of its critical assumptions, such as economizing action and spatial differences. Although this worry is understandable, it does not pay enough attention the practice of modeling in economics and elsewhere. In seeing the world through the lens of robustness analysis, philosophers presume that modelers know at the outset which of their unrealistic assumptions are just tractability assumptions, and which are important for explaining real-world cases. This presumption is rarely true. Economists (and other scientists such as evolutionary biologists) build models to explore the possibilities in the model world and to learn about critical dependencies. Non-robust results may point out unexplored possibilities and help us discover which of a model's assumptions were critical in deriving its results.

In evaluating the worry about robustness, we also need to consider the following question. If slightly different conditions produce different outcomes in the real world, should we still consider robustness as a virtue? Perfect markets are all alike, but every imperfect market is imperfect in its own way. In the world of imperfect competition, slightly different market conditions do not always produce similar outcomes. Economists build models to explore these possibilities. We have seen that in Hotelling's time, the world of imperfect competition was

[13] Catherina Marchionni made this point in her talk entitled "Mechanisms, Explanation and Confirmation in Theoretical Economics" at the LSE Conference "Explanation, Normativity, and Uncertainty in Economic Modelling", 16–17 March 2016, London, UK.

mostly an unexplored territory. The non-robustness of Hotelling's results inspired economists to explore new explanatory dependencies and hence further expand the range of possible explanations available to them.

Finally, let us consider Hotelling's contribution in the broader context of industrial economics. How does Hotelling's model fit into the economists' quest to understand industrial organization?

Consider the following "awkward facts" concerning markets.

> (1) Many industries, including most that produce consumers' goods, produce a large number of similar but differentiated products. […] (2) The consumers' goods produced by different firms in the same industry are differentiated from each other so that two products produced by two different firms are rarely, if ever, identical. […] (3) The set of products made by the firms in any one industry is a small subset of the set of possible products. […] (4) Any one consumer purchases only a small subset of the products that are available from any one industry. […] (5) Consumers perceive the differences among differentiated products to be real and there is often approximate agreement on which ones are, and are not, close substitutes. […] (7) Tastes are revealed to vary among consumers because different consumers purchase different bundles of differentiated commodities and these differences cannot be fully accounted for by differences in their incomes. (Eaton and Lipsey 1989, 725–26)

These observations that are in need of explanations are about just one topic in industrial economics: product differentiation. How can we explain these facts? What are their consequences and policy implications? It is almost impossible to answer questions concerning all of these facts using a single model. Since such a model would be intractable (Eaton and Lipsey 1989, 726), economists use a diversity of models to answer these questions (Rodrik 2015; Aydinonat 2018). In order to understand product differentiation in markets, one needs to have a good grasp of these and other models of product differentiation and competition. Hotelling's model sparked the development of a subset of these models, known as address models. It improved the ability of economists to ask and answer *what-if* questions, and to explain economic phenomena. Perhaps a more straightforward way to appreciate the relevance and value of Hotelling's model is to ask ourselves whether leaving Hotelling's contribution out of industrial economics would cripple our understanding of imperfect competition. It would.[14]

We argued that although Hotelling's model does not directly explain any particular real-world phenomena, it *helps us explain* economic phenomena. "How does it help?", the reader may still ask. Let us close this section by answering this question. Thanks to Hotelling, when we see two gas stations next to each other on an intercity road, or when we recognize that all toothpastes are almost the same but not exactly so, we can start sketching a *how-possibly* explanation. Having a how-possibly explanation is important, but correctly explaining these

[14] We thank the anonymous referee who suggested this alternative way of expressing the relevance of Hotelling's model.

facts (i.e., a how-actually explanation) requires evidence concerning the existence and effectiveness of the proposed explanatory factors. Again, thanks to Hotelling and the economists who followed him, we have a better idea of what to look for and where to look for it. So, not only does it help in sketching how-possibly explanations, but also in selecting among possible explanations. Hence, Hotelling's model and its modern variations contribute to explanations of particular instances of minimum and maximum product differentiation. Consider, for example, explanations of why competing airlines schedule their departure times very close to each other (Salvanes, Steen, and Sørgard 2005; Borenstein and Netz 1999), or why gas stations are clustered rather than evenly distributed on highways (Netz and Taylor 2002). It turns out that when prices are regulated there is less differentiation in terms of flight departure times both in USA (Borenstein and Netz 1999) and Norway (Salvanes, Steen, and Sørgard 2005), and the tendency of firms to locate next to each other help us explain what happens when there is more price competition in the airline industry: less clustering. The same applies to the location of gas stations: with greater competition, there is more differentiation (Netz and Taylor 2002). In each of these examples, explaining a particular case requires considering Hotelling's suggested explanatory factors as well as other related models that hint at other factors and outcomes. Explaining a particular case also requires checking whether these factors were effective in producing the observed result and checking for the effects of other possible factors. Hotelling's model will not explain all cases, but if it were not available as a possible explanation, our actual explanations would have suffered.

In sum, the set of models developed by Hotelling and others provides economists with a menu of possible explanations, a sketch of how the explanation could go, and a guideline for what evidence to seek in order to explain particular situations. Hotelling's mistaken model was an important and explanatory model, because it improved the ability of economists to explain particular cases by way of contributing to this menu of explanations in a significant way. Back in 1929, it expanded the available menu of possible explanations, contributing both to the set of *explanantia* and *explananda*.

Conclusion

Hotelling's model presented a challenge because it was deficient in three important respects that common sense and many philosophical accounts require for explanatory value. Not only was it highly unrealistic and non-robust, it was also mistaken. We argued that, in order to see the explanatory value-added of Hotelling's model, one needs to go beyond these three criteria and evaluate it in its relevant historical context. We showed that Hotelling accomplished at least five things at once. First, he challenged the presumptions concerning the welfare implications of profit-maximizing behavior in real world markets. Second, he proposed a new theoretical explanation of the stability of competition in models of imperfect competition. Thus, he offered a solution to an existing theoretical question by introducing location and transportation costs in order to account for product differences and the fact that in imperfectly competitive markets consumers may have reasons for preferring one product over the other despite differences in price—hence reformulating the principle of one price in order to make it applicable to imperfect competition. Third, he expanded the set of *explanantia* by suggesting a set of new explanatory factors that could be conceptualized using location and transportation

costs as proxies for product differentiation in markets. Hence, Hotelling expanded the menu of possible explanations in the theory of imperfectly competitive markets. Fourth, he expanded the set of *explananda* by alerting economists to observations in need of explanations: the excessive sameness in markets, and the existence of "monopoly" profits in the presence of competition between two (or more) firms. He also suggested that his model could explain non-market phenomena, like competition between political parties; thus, he further expanded the set of *explananda*, and the menu of possible explanations. Finally, he introduced a workhorse model, or a modeling framework that turned out to be useful in analyzing other aspects of imperfectly competitive markets. Hence, he contributed to the future expansion of the menu of possible explanations in the theory of imperfectly competitive markets.

Although we focused on Hotelling's model, the general lesson from this exercise is that by combining historical and philosophical analysis, we can achieve a better understanding of the epistemic import of highly unrealistic economic models.

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